THE DEVELOPMENT OF PERMISSIBLE REQUIREMENTS FOR SAFE UNDERGROUND DIESEL HAULAGE

BY M. A. ELLIOTT AND R. S. JAMES

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INTRODUCTION

Diesel-powered haulage equipment has recently been tested and approved for permissibility by the Bureau of Mines for use in mining in the United States. Achievement of this advance in safety involved extensive studies, both in the testing station (2, 3, 20, 21, 22, 23, 24, 25, 26, 27)3/ and in the field 1, 4, 13, 30), of the operating characteristics of diesel engines in relation to the use of such engines underground. The results of these studies formed the basis for establishing the requirements that should be met by diesel-powered haulage equipment approved for permissibility.

Considerable interest has been manifested in the development of diesel-powered haulage equipment for mines. The purpose of this paper is to retrace briefly the course of this development and to answer such questions as:

What is the history of the use of diesel engines underground?

Why has the Bureau of Mines been interested in the development of diesel-powered haulage equipment for use in mines?

What factors must be considered to insure safety in the use of diesel engines in mines?

What characteristics of the diesel engine make it feasible to use such engines underground? What performance tests and requirements have been developed to assure safe operation of diesel engines in mines?

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HISTORICAL REVIEW OF USE OF DIESEL MINE LOCOMOTIVES

Diesel locomotives were first used in coal mines in Germany in 1927 (12, 31). Shortly thereafter such locomotives were used in the coal mines of Belgium (7) and France and in 1939 the first diesel locomotive was used in a British coal mine (12). Before World War II the number of diesel locomotives in use in coal mines on the Continent was as follows:

3/ Underlined numbers in parenthesis refer to items in the bibliography at the end of this report.

	Number of units	Year
Western Germany	340	1938
Eastern Germany	10	1938
Belgium	114	1939
France	380	1937
Great Britain	-	-

Considerable interest in European developments in the use of diesel-powered haulage equipment for mining and tunneling was indicated to the Bureau of Mines by engineers responsible for such work (31). In addition, the Bureau of Mines and other organizations engaged in promoting safety in mines in the United States were interested in development of diesel-powered haulage equipment that was approved for permissibility to replace the hazardous electric trolley locomotive. The Bureau has recognized for some time the importance of eliminating the hazards associated with underground haulage systems using bare trolley wires (17). For example, 30 to 40 fatalities occur each year as a result of electrocution by contact with bare trolley wires. Furthermore, in 1943 and 1944, 101 men were killed and extensive property damage resulted from mine fires started by falls of roof grounding bare trolley wires.

Because of the potentialities of the diesel locomotive in improving safety in haulage operations, the Bureau of Mines began its investigation of the use of diesel engines underground to provide the technical information necessary to assist this development in the United States (28). The Bureau's work in this field was begun in 1937, soon after the development of high-speed automotive-type diesel engines had reached an advanced stage in the United States, and has been continued since that time; it included studies both in the testing station (2, 4, 13, 14, 18, 19) and in the field (1, 4, 5, 16). The most extensive field studies in which the Bureau of Mines collaborated involved the use of diesel locomotives in the construction of the Delaware aqueduct (1, 4). These studies extended over a period of several years and furnished valuable practical information on the use of diesel-powered haulage equipment underground.

Based on information obtained in the testing station and the field, in 1944 the Bureau of Mines issued a permissibility schedule (8)for diesel mine locomotives that may encounter flammable atmospheres underground. In 1949 a schedule (10) was issued covering the approval of diesel-powered equipment in underground workings in which the possibility of encountering flammable atmospheres does not exist.

After World War II several equipment manufacturers undertook the development of diesel-powered haulage equipment that would conform to schedules 22 and 24. In 1951, after extensive testing, approvals were granted for a permissible diesel-powered mine locomotive conforming to the requirements of schedule 22 and for an approved diesel-powered haulage unit (diesel electric shuttle car) conforming to the requirements of schedule 24.

This brief review of the development of diesel mine-haulage requirements emphasizes the conservatism of the Bureau of Mines in relation to this development. For example, the Bureau evaluated 10 years of successful operating experience with diesel locomotives in coal mines in Europe before considering the possible application of this development to mining in the United States. Then an independent investigation was made of diesel engines manufactured in this country and used under mining conditions in the United States. In the course of these investigations, it became apparent that diesel-powered haulage equipment could be made safer than

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trolley locomotives. This conclusion, therefore, answers the question as to why the Bureau of Mines has been interested in the development of approved diesel-powered haulage equipment for use in mines.

SAFETY CONSIDERATIONS IN USING DIESEL ENGINES UNDERGROUND

Diesel-powered haulage equipment eliminates the need for exposed trolley wires and thus removes one of the chief hazards associated with the operation of trolley locomotives. However, experience with diesel mine locomotives in Europe and investigations of the Bureau of Mines have shown that, as with any piece of equipment, adequate safeguards must be provided to insure and maintain safety under all possible operating conditions. It has been found that the following three factors are important in determining what factors must be considered to insure safety in the use of diesel engines in mines:

1. Ventilation must be provided to maintain a healthful working enviroment.

2. The intake and exhaust openings of the engine used in gassy mines must be protected by flame arresters to avoid gas-ignition hazards, and all engine surfaces must be maintained at a temperature below 400° F. to reduce fire hazards.

3. Even though diesel fuel has a high flashpoint, suitable precautions must be observed in handling diesel fuel underground to reduce fire hazards.

These factors will be discussed later in more detail, and it will be shown that the inherent operating characteristics of the diesel engine simplify the problem of providing adequate safeguards and make it possible to attain a high degree of safety.

CHARACTERISTICS OF DIESEL ENGINES THAT MAKE THEM ADAPTABLE TO UNDERGROUND USE

The question might be raised as to why safety organizations were willing to consider the use of diesel engines underground, since such organizations had discouraged and prevented the use of gasoline engines underground in the United States. The answer to this question may be found in the inherent characteristics of the diesel engine, which permit it to be used safely underground. The more important of these characteristics are as follows:

1. Diesel fuel is safer to handle than gasoline.

2. The diesel engine operates with a large excess of air so that combustion is substantially complete, and the production of harmful and objectionable gases is minimized.

3. The diesel engine does not require an electrical ignition system because the fuel, which is injected at the end of the compression stroke into air at a high temperature and pressure, ignites spontaneously by direct chemical reaction with air under these conditions.

If the first two characteristics are examined in greater detail, it is possible to demonstrate clearly the greater inherent safety of the diesel engine. For example, diesel fuel has a flashpoint ranging from 120° to 230° F., (6, pp. 8-11) whereas the flashpoint of gasoline is below 0° F., frequently as low as -50° F. As the flashpoint is the temperature that must be reached before the mixture of fuel vapor and air above the surface of the liquid fuel can be ignited by a flame, it is apparent that the fire hazard in handling diesel fuel is much less than the fire hazard in handling gasoline. The greatly reduced fire hazard presented by diesel fuel is one important reason for the substitution of diesel locomotives for gasoline locomotives in European coal mines. The importance of this substitution was emphasized by two mine disasters in France in 1929 and 1930, which were attributed to the ignition of gasoline or gasoline-air mixtures underground. The low flashpoint and high volatility of gasoline, which make possible the formation of flammable gasoline-air mixtures at ordinary temperatures, were the basic factors responsible for these disasters. If the use of diesel fuel is considered under similar conditions, it is evident that flammable mixtures of fuel vapor and air cannot be formed at ordinary temperatures (below 100° F.), because the flashpoint is 120° F. or greater. This property of diesel fuel is very important in relation to the use of diesel engines underground; by reason of it diesel fuel can be handled more safely than gasoline.

The second characteristic of the diesel engine that makes it feasible to use such engines underground is its ability to use fuel efficiently. This means that combustion is substantially complete, and the minimum of harmful and objectionable gases is discharged in the exhaust. This characteristic of the diesel engine is a result of the manner in which fuel and air are supplied and utilized. The diesel engine takes into the cylinders a full charge of air on every stroke, regardless of the load on the engine. Variations in load are taken care of by supplying more or less fuel to the engine, depending upon whether the engine load increases or decreases. The fuel is controlled with extreme accuracy and is injected into the hot compressed air at the end of the compression stroke. The fuel-injection system is set and sealed to limit the maximum quantity of fuel that can be injected. This limitation on the quantity of fuel that can be supplied to the engine is such that the air in excess of that needed for complete combustion will always be greater than 20 to 40 percent, depending upon the type of engine. Under such conditions, combustion is virtually complete, and the production of such products of incomplete combustion as carbon monoxide and aldehydes is so minimized that the mine can be adequately ventilated to maintain a healthful working enviroment by diluting and carrying away the exhaust gases. The ventilation required for the other products of combustion - carbon dioxide and oxides of nitrogen - is also well within practical limits.

If the operating characteristics of a gasoline engine are compared with those of a diesel engine, it is evident that the use of gasoline engines underground creates hazardous conditions in addition to those associated with handling the highly volatile and flammable gasoline fuel. For example, if a gasoline engine operates in a place where too little air is supplied to burn the fuel completely, its exhaust gases will contain high concentrations of carbon monoxide. In fact, the concentration of carbon monoxide may be so high that under the somewhat restricted conditions of underground workings dangerous local concentrations could be present in the working enviroment even if adequate overall ventilation were supplied. This fact, coupled with the necessity for an electrical ignition system and the fire hazard of the fuel, makes the gasoline engine completely unsuitable for underground use.

The mining laws of some States (28) prohibit the use of internal-combustion engines underground. The laws originally were drafted specifically to prevent the use of gasoline engines underground and it is unfortunate that the broader term "internal-combustion engine" was used because this includes the diesel engine and in some instances has created the erroneous impression that the hazards of operating diesel and gasoline engines underground are comparable. It is hoped that this erroneous impression will be corrected by the foregoing discussion, which has shown that the diesel engine has inherent characteristics that make it much safer than the gasoline engine and permit it to be used safely underground. Passage of House Bill 1604 by the General Assembly of the State of Pennsylvania may be a step in this direction. This legislation, passed on December 22, 1951, and signed by the Governor on December 27, 1951, as Act 479, states in part "that the secretary of mines may, if he is satisfied that it will not be injurious to the health or safety of the employees, authorize the use of Diesel-powered machinery under such reasonable general or special rules and regulations as he may from time to time promulgate."

PERFORMANCE TESTS OF SAFETY FEATURES

Toxic Gases

In developing tests that would enable Bureau engineers to analyze the exhaust gases produced under all conditions, it was realized that laboratory tests should be made over the range of engine operating speeds and loads up to and including the maximum possible output of the engine. Even these, however, were not considered severe enough to insure adequate safety for gassy coal mines. It was therefore planned to make additional tests in which approximately 1-1/2 percent natural gas was added to the intake air to check results for the possibility of a locomotive (schedule 22) running into some gas even in the haulageways; the 1-1/2 percent value corresponds to the limiting value set forth in the Federal Mine Safety Code for Bituminous-Coal and Lignite Mines of the United States, Article V, Section 5d. Under all test conditions, the exhaust gases from the engine are analyzed to determine the concentration of carbon monoxide, carbon dioxide, oxides of nitrogen, aldehydes, and oxygen.

The concentrations of the various gases that may be permitted in an underground atmosphere are stated in schedules 22 and 24 as follows:

Carbon dioxide (CO_2) - not more than 0.5 percent by volume.

Carbon monoxide (CO) - not more than 0.01 percent by volume.

Oxides of nitrogen ($NO + NO_2$) - not more than 0.0025 percent by volume.

Oxygen (O_2) - not less than 19.5 percent by volume.

Aldehydes (as equivalent formaldehyde) - not to exceed 10 p.p.m.

The limits given above for carbon dioxide and oxygen are the same as those listed in the Federal Mine Safety Code for Bituminous-Coal and Lignite Mines of the United States, Article V, Section 5a. The limit for carbon monoxide given above is the same as that listed in American Standards Association Z37.13-1944 approved January 19, 1944; and the limit for aldehydes (as equivalent formaldehyde) corresponds to that given in American Standards Association Z37.16-1944 approved May 18, 1944.

From analysis of the exhaust gases, calculations are made to determine the volume of ventilating air that would be required for diluting each constituent to the limit set. The minimum ventilation for the mine is then based upon the highest air requirement calculated. By making the tests with the 1-1/2 percent natural gas in the intake and calculating the air requirements as above, a safe value is provided; however, this quantity of air is multiplied by a factor of 3 for coal mines to provide additional safety. Tests for non-coal-mine equipment are made only with normal air (that is, without natural gas) supplied to the intake of the engine, and the minimum volume of ventilating air, calculated as above is multiplied by a factor of 2. It should be remembered that the foregoing calculated ventilation assumes continuous operation of the engine under load, whereas in practice an engine probably will operate less than 50 percent of the time under these conditions, so here, again, the requirements are on the safe side.

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Dilution of Exhaust Gas

The raw exhaust from an engine must be diluted with enough air to reduce the concentration of harmful gases before they are discharged into the underground atmosphere. Practical considerations indicated that a dilution ratio of 25 to 1 was feasible. On this basis, it would be possible to permit 0.25 percent carbon monoxide in the undiluted exhaust and to maintain a maximum concentration of 0.01 percent carbon monoxide in the diluted mixture discharged from the unit. Accordingly, Bureau schedules 22 and 24 require that the undiluted exhaust gas (as it comes from the engine) shall contain not more than 0.25 percent, by volume, of carbon monoxide. Raw exhaust gas is usually diluted by mixing the exhaust gases with the cooling air from the engine radiator fan before being discharged into the surrounding atmosphere. This diluted mixture must, under any and all conditions, meet the generally accepted hygienic standards already stated.

The requirements included in Bureau diesel schedules are the result of a number of years of research and experience, both in the testing station and in the field. It is believed that these diesel requirements are in general more strict than those of most other countries.

Explosion Tests

In the event that the diesel locomotive (schedule 22) should run into an explosive atmosphere, it would be required to be explosion-proof, and so Bureau schedule 22 includes the specifications that must be met and describes the tests to be made to insure that the locomotive is safe in this respect.

In the early stages of explosion testing of diesel engines and their auxiliaries, it was very difficult to obtain ignitions of natural gas and air mixtures surrounding the engine and its auxiliary equipment. For example, 1 diesel engine having its exhaust manifold removed and its exhaust ports opening directly into an inflammable mixture of 9 percent natural gas in air did not cause a single ignition during a total of 100 hours of running at various loads and speeds. Actually, it was found that erratic engine operation with resulting engine backfiring was necessary to cause ignitions of the gas in the testing gallery. As a result, in addition to making tests of the engine and auxiliaries completely surrounded by inflammable gas and air mixtures, tests are also made using spark plugs at various points in the system to deliberately ignite the internal mixtures. These tests using spark plugs are made in both flowing explosive mixtures and static explosive mixtures; to pass permissibility tests, the equipment must not ignite the surrounding explosive atmosphere and must not permit egress of flames.

Many explosion tests are made to insure that all possibilities of circumstances are checked; the actual number of tests may run into the hundreds.

The flange fits (15), bolting, and strength of enclosures must meet the same requirements that have applied to electrical enclosures on permissible electrical equipment (9) for years. To protect the intake and exhaust openings of the engine, flame arresters are provided for the intake manifold and exhaust conditioner. Special study (29) of flame arresters was made to supplement data already available and experience obtained from many tests of similar devices used on certain electrical compartments.

Electrical parts, such as headlights, starters, and generators used on diesel equipment are given the same inspections and tests that components used for permissible elctrical machines are given. These compartments are smaller in general than

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those used on electrical machines and can be made strong and adaptable to explosion-proof diesel use quite readily.

Fire Precautions

Diesel fuel, because of its relatively high flashpoint, is much safer to handle than many liquid fuels. However, to minimize fire hazards, schedules 22 and 24 require that diesel fuel for underground use must have a flashpoint of not less than 150° F. (8, p.30).

Schedules 22 and 24 recommend precautions to be used in handling diesel fuel, and give other requirements for minimizing fire hazards. For example, surface temperatures of the equipment must be below 400° F. under the most stringent operating conditions. Most of the time these temperatures will be much lower. The temperature of the final exhaust must not exceed 160° F. These requirements mean that most of the surfaces of engine, exhaust manifold, exhaust piping, and exhaust conditioner will be water cooled and will therefore minimize the fire hazard. The 400° F. surface-temperature limitation was originally set to prevent fires from coal dust or grease and oil on heated surfaces of electrical compartments on permissible electrical machines.

Schedules 22 and 24 require that at least one fire extinguisher of the liquid carbon dioxide type be carried on approved diesel machines.

FINAL INSPECTION

A final inspection of each new design of a diesel machine must be made, and this can best be done at the factory or mine. At this time, mechanical features can be checked, such as guards for gears or chains, protection of the operator, and strength of various materials and parts, particularly with regard to protection against roof falls. Observations are made to check proper location of instruments and controls. Additional samples of exhaust gases are taken during the final inspection. Samples of raw gas are taken at or near the exhaust manifold outlet and near the point of discharge from the machine with the engine idling and also loaded. Analysis of these samples shows the ratio of dilution and the composition of the air around the machine. The electrical compartments are checked for safe location, and wiring is checked for protection from damage and proper clamping.

MAINTENANCE OF SAFETY FEATURES IN ACTUAL SERVICE

The development of any machine can hardly be considered complete at the time the first design is settled upon and the actual construction is finished. It is generally agreed that any new piece of equipment must be tested under actual service conditions to show the designers what changes are needed to really "smooth out" the design. Usually, however, these changes are minor, and the main item that determines the day-by-day performance of any vehicle is the maintenance it receives. The general condition of the machine should be checked each time it is put into service. One important daily item of maintenance for the diesel machine concerns the exhaust conditioner (scrubber). The water makeup tank should be filled daily to insure that enough water is available for the exhaust-conditioning system. If a locomotive or other machine is used on a two- or three-shift basis, water may have to be added more than once each day, depending on the duty cycle and the water capacity of the system. This system should be drained and flushed once or twice each week.

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Mechanics should see that all filters are clean and in proper condition, all parts of the intake and exhaust systems are free of obstruction, all joints are tight, all cylinder head bolts are tight, and all electrical enclosures are in proper condition. The locomotive should be maintained in accordance with detailed instructions furnished by the manufacturer (8, p. 27).

It is quite unlikely that mine mechanics will have equipment suitable for servicing injector valves and diesel-type fuel pumps. It is therefore advisable that these parts of the equipment be removed and replaced with new or factory-rebuilt parts, in accordance with the recommendations of the engine manufacturer. To correct carburetor trouble on an automobile these days, a mechanic seldom overhauls it himself - he replaces it with a new or factory-rebuilt assembly. If this method of replacement is used with approved diesel equipment, the benefit of the fine fits and accurate calibration of factory tools and trained personnel is obtained. It is believed that this method is also the least expensive in the long run. Such a plan of maintenance would also mean that few, if any, special tools would be needed by the mine mechanic for work on diesel equipment.

SOME OPERATIONAL INFORMATION

Some may question the safety of equipment approved for permissibility after considerable use. A person may feel safe with a new machine but have doubts about the maintenance that will be provided and wonder particularly what effect time and use will have on the toxicity of the gases in the atmosphere.

The following information was taken from a memorandum with tabulated data (table 1) by L. B. Berger regarding atmospheres where diesel engines were used underground and is

> - - - - a tabulation made of all data that we have accumulated in the Health Branch as the result of analyzing samples of mine and tunnel atmospheres collected by Bureau personnel in situations where diesels were used underground. These samples represent only the general atmospheres of the underground places; the tabulation does not include samples of undiluted engine exhaust gas. The tabulation does not take into account rate of ventilation, make or type of diesel equipment, or nature of the operations in which the diesels were used. The tabulation merely summarizes information obtained to date by the Bureau on the effect of diesel operation upon the quality of the air in underground places. The gases considered in the tabulation are carbon dioxide, oxygen, carbon monoxide, and oxides of nitrogen. One hundred sixty-nine samples have been analyzed for the first three gases, and 152 samples for oxides of nitrogen. These samples represent the total analyzed by the Health Branch from 1939 until the present. The results of the tabulation are presented in statistical form in table 1.
>
> Analysis of the data indicates that in only one instance did carbon dioxide exceed the generally recognized maximum allowable concentration of 0.5 percent, and that the majority of the values were well below this figure.
>
> Oxygen was never observed as less than 20 percent.
>
> Ninety-six percent of the samples contained less than 0.01 percent of carbon monoxide, the generally recognized maximum allowable concentration, and only 4 samples (2.4 percent of the total) exceeded this value. One of these four samples, which contained 0.03 percent carbon monoxide, was taken after blasting and the carbon monoxide may be attributable to the explosive rather than the diesel.

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TABLE 1. - Observed ranges of concentration of CO_2, O_2, CO, and oxides of nitrogen in atmospheres of underground operations where diesels were in use

Range of concentration of CO_2, percent by volume	0.03-0.10	0.11-0.20	0.21-0.30	0.31-0.40	[1]0.41-0.50	More than 0.50		Total
Number of samples	100	51	15	1	1	[3]1		169
Percent of total	59.1	30.2	8.9	0.6	0.6	0.6		
Cumulative percent	59.1	89.3	98.2	98.8	99.4	100.0		
Range of concentration of O_2, percent by volume	20.93-20.80	20.79-20.60	20.59-20.40	20.39-20.20	[2]20.19-20.00			
Number of samples	110	48	9	1	1			169
Percent of total	65.1	28.4	5.3	0.6	0.6			
Cumulative percent	65.1	93.5	98.8	99.4	100.0			
Range of concentration of CO, percent by volume	0	Less than 0.0025	Less than 0.005	Less than 0.01	[1]0.01	More than 0.01		
Number of samples	101	28	23	11	2	[4]4		169
Percent of total	59.7	16.6	13.6	6.5	1.2	2.4		
Cumulative percent	59.7	76.3	89.9	96.4	97.6	100.0		
Range of concentration of oxides of nitrogen, p.p.m.	0	0-5	6-10	11-15	16-20	[1]21-25	More than 25	
Number of samples	64	22	32	21	2	6	[5]5	152
Percent of total	42.0	14.5	21.1	13.8	1.3	4.0	3.3	
Cumulative percent	42.0	56.5	77.6	91.4	92.7	96.7	100.0	

[1] Maximum allowable concentration.
[2] Minimum allowable concentration.
[3] Concentration of CO_2, 0.64 percent.
[4] Three samples contained 0.02 percent and one 0.03 CO.
[5] Concentrations were 26, 28, 30, 31, and 54 p.p.m. oxides of nitrogen.

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Approximately 97 percent of the samples did not contain more than 25 p.p.m. of oxides of nitrogen, the maximum allowable concentration. Of the five samples that exceeded this value, four were quite close to it, and may have exceeded it only by the margin of possible analytical error. The fifth sample, which was reported as containing 54 p.p.m., was suspected by the analyst of having been contaminated during sampling, and therefore may not be representative.

These data obtained by the Bureau to date do not indicate that significant contamination of underground atmospheres by carbon dioxide, carbon monoxide, oxides of nitrogen, or by depletion of oxygen, has been caused by the observed diesel operations.

It should be remembered that the preceding information was obtained from diesel trucks and other vehicles as well as diesel locomotives and that none of the equipment was of a permissible or approved design.

At a meeting of the National Safety Congress in October 1951, A. E. Crook (11) stated that he did not know of a single case of a worker having been overcome from the exhaust gases of a mine diesel locomotive in Great Britain or Europe.

Inexpensive testing equipment is available with which the atmosphere surrounding a piece of diesel equipment may be quickly approximated for carbon monoxide, and a constant check on the operating condition of the engine and system can be made simply by observing the exhaust, since any black smoke is an indication of incorrect fuel-air ratio and resultant increase in carbon monoxide.

SUMMARY AND CONCLUSIONS

The development of permissible diesel-powered haulage equipment represents an important step forward in promoting safety in underground haulage because safe diesel-powered equipment is now available as an alternate to the hazardous electric trolley locomotive. This advance in safety was made possible (1) by taking full advantage of certain desirable operating characteristics of the diesel engine and (2) by maintaining the same high standards for any necessary protective equipment that have been set for permissible electrical equipment approved by the Bureau of Mines. The results of studies both in the testing station and in the field formed the basis for establishing the requirements that should be met by diesel-powered haulage equipment approved for permissibility. The more important of these requirements are:

1. Proper ventilation must be provided to maintain a healthful working enviroment.

2. Where explosive gases or dusts may be encountered, intake and exhaust openings of the engine must be protected by flame arresters, and all flame passages or possible arc-producing parts must be enclosed in explosion-proof housings.

3. All surfaces must be maintained at temperatures below 400° F., and other adequate precautions must be observed to minimize fire hazards.

4. Adequate regular maintenance must be provided for haulage equipment in service.

Test procedures have been developed to insure that equipment approved for underground use meets the stringent requirements of schedules 22 and 24. Equipment passing these tests is adequately safeguarded for underground use, and the development of such equipment offers opportunities for significant advances in safety in underground haulage.

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